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Request for grant of a patent

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1. Your reference	z80139 CMAp	
2. Patent application number *(The Patent Office will fill in this part)*	9805646.8	18 MAR 1998
3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	BICC Public Limited Company Devonshire House, Mayfair Place London, W1X 5FH, GB, and Metal Manufactures Limited Level 33, Gateway, 1 Macquarie Place Sydney, NSW 2000, Australia	
Patents ADP number *(if you know it)*	1834004 5848336001	
If the applicant is a corporate body, give the country/state of its incorporation	Gt. Britain Australia	
4. Title of the invention	Superconducting Tapes	
5. Name of your agent *(if you have one)*	~~Michael John Poole~~	
"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	~~BICC Patents & Licensing Department Quantum House, Maylands Avenue Hemel Hempstead, HERTS. HP2 4SJ~~ RGC Jenkins & Co 26 Caxton Street London SW1H 0RJ Great Britain	
Patents ADP number *(if you know it)*	70981890001	

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number	Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application	Number of earlier application	Date of filing *(day / month / year)*

7. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:* *a) any applicant named in part 3 is not an inventor, or* *b) there is an inventor who is not named as an applicant, or* *c) any named applicant is a corporate body.* *See note (d))*	YES

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9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	-
Description	7
Claim(s)	2
Abstract	1
Drawing(s)	1

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Priority documents	-
Translations of priority documents	-
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	-
Request for preliminary examination and search *(Patents Form 9/77)*	-
Request for substantive examination *(Patents Form 10/77)*	-
Any other documents *(please specify)*	-

11. I/We request the grant of a patent on the basis of this application

Signature MJPoole Date 17 March 1998

M.J. Poole - Agent for the Applicant

12. Name and daytime telephone number of person to contact in the United Kingdom M.J. Poole - 01442 210100

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SUPERCONDUCTING TAPES

The present invention relates to superconducting tapes, particularly, although not exclusively, for carrying alternating current (AC). Superconducting tapes can be used to make coils, magnets, transformers, motors and generators as well as current carrying cables.

Tapes comprising superconducting material, and referred to as superconducting tapes, are already known, and comprise one or many superconducting filaments in a medium of silver or silver alloy. The main class of superconducting tape (powder-in-tube or PiT tape) is made by drawing or otherwise reducing a tube of silver, or less usually silver alloy, filled with a powder form of the superconducting oxide (or its precursor), and rolling or otherwise forming it into a thin tape. Multifilamentary tapes are mostly made by grouping filled tubes in a common silver (or alloy) sheath at an intermediate stage of reduction.

One important superconducting oxide is known as Bi-2223, and is a compound oxide of bismuth, strontium, calcium, and copper (for which certain limited substitutions can be made) (or it can be considered a cuprate salt).

Known tapes usually have a thickness of between around 0.2 mm and 0.3 mm, and a width of between 2 mm and 5 mm. The superconducting filaments must be thin, typically, around 10 to 40 microns in thickness, to obtain an adequate critical current, and they typically have an aspect ratio of around 1:10. The filaments comprise many plate-like grains, and for good performance, the grains should be, as much as possible, aligned in the same crystallographic orientation. The relative orientation is often referred to as the grain alignment or "texture". Thin, well textured filaments allow a high critical current, and give overall flexibility to the whole tape.

Composite tapes are sometimes made by forming a stack of individual tapes and wrapping the stack with one or more tapes (usually of silver) to keep it together, and in another application filed today we have proposed an improved form of composite tape in which the individual tapes are diffusion-bonded, eliminating the need for a wrapping tape and the otherwise inevitable gaps and/or overlapping between the turns of the wrapping tape that create kinks in the filaments and so destroy local grain alignment leading to degradation of the overall critical current density J_c.

In accordance with the present invention, a composite superconducting tape comprises a multiplicity of constituent superconducting tapes stacked parallel to one another with major faces in contact, and is *characterised in that* at least some of the constituent tapes have widths not greater than half the width of the composite superconductor and are laid edge to edge with each other.

Preferably all the constituent superconducting tapes have a width that is substantially half, or another simple fraction, of the width of the composite tape so that they form two or more substacks with aligned zones between them which contain no superconducting material. This will normally require the addition of a full-width tape of silver or silver alloy to bridge from tape to tape, to provide sufficiently strong mechanical connection between the substacks. Preliminary experiments lead us to believe that this structure has substantially lower A C losses compared with a stack of the same overall dimensions and composition with all full-width superconducting tapes; while we do not wish to be bound by any theory, it is thought that this observation may be accounted for by magnetic de-coupling between the substacks.

Preferably the full-width metal tape proposed is at one end of the stack, or two tapes may be provided, one at each end of the stack; if there is only one metal tape or two tapes are of unequal strength, performance may be enhanced if the tape is used in a construction in which the tape, or the stronger tape, is always on the convex side of any curve, as more fully explained in another application filed today.

Alternatively one full-width superconducting tape might be used, but we do not expect this to achieve the full benefit of the invention as the opportunities for de-coupling across the zones between the substacks are lessened.

Preferably the superconducting tape is diffusion-bonded and all its elongate components extend longitudinally, as described in yet another application filed today.

In the preferred forms of the invention in which a metal tape is used, such tape is preferably flat and has a width not substantially greater than that of the superconducting tapes (it might be slightly less). However, if desired a wider metal tape which is, or subsequently becomes, bent to a channel section could be used; this would have structural advantages but would adversely affect fill factor. Similarly the use of a silver foil (or other compatible material) wrapped around the stack but extending longitudinally is not excluded, but we presently think it unnecessary and undesirable, especially as there tends always to be more silver than is useful at the edges of the constituent tapes.

Diffusion bonding of the superconducting tapes (and metal tapes, if present) can be obtained by assembling them face to face and heat-treating at a temperature low enough to avoid any deleterious effect on the superconducting material (or its precursor, as the case may be); when the superconducting material has a typical BISCCO-2223 composition, the temperature should not exceed 842°C; provided

control is close enough, a temperature of 840°C is recommended. A diffusion time at temperature of several hours will be required to achieve adequate bonding; on the other hand, excessively long periods are undesirable as tending to produce too much sintering of the superconductor material.

Preferably the diffusion-bonded stack of tapes is rolled to reduce overall thickness, and this may also strengthen the bonding.

The invention will now be described, by way of example only, with reference to the accompanying diagrammatic drawings (not to scale) in which each figure is a cross-section of one form of composite superconducting tape of the present invention.

The composite superconducting tape shown in Figure 1 has a width of between 4 and 5.5 mm and a thickness of about 0.27 mm and comprises (for example) eight stacked monofilamentary tapes 12 bonded together. Each monofilamentary tape 12 comprises a filament 5 of superconducting material, for example, BISCCO-2223 in a silver/silver alloy cladding 7 as with known superconducting tapes. Typically (in the finished product as shown) each individual monofilamentary tape 2 has a thickness of 50 μm and the filaments 5 themselves have typical thicknesses of 10 to 40 μm. The constituent tapes 12 each have a width substantially equal to half the width of the composite tape and they are arranged with a full-width silver bridging tape 13 in two sub-stacks 15 with a zone 16 between them that is substantially free of superconductor filaments.

The tape of Figure 2 is similar except that there are silver and/or silver alloy tapes 13 and 14 at both the top and the bottom ends of the stack.

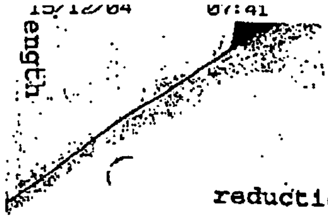
To make either of the superconducting multifilamentary tapes shown in the drawings, the required number of monofilamentary tapes 2 must be made. The monofilamentary tapes 2 are made by firstly packing BISCCO-2223 oxide powder (or more usually a precursor convertible to the -2223 composition by heat-treatment) into a cleaned and dry tube of silver or silver alloy having an internal diameter of approximately 8 mm and an external diameter of approximately 10 mm. A length of between 4 cm and 6 cm - depending upon the length of the silver tube - at one end of the tube is then swaged, and the tip of the swaged end closed off using smaller swaging dies, to prevent powder loss during packing. After swaging, the tube is again dried. The prepared tube is then carefully filled with the superconducting powder (precursor) under dry argon in a glove box. The powder is added small amounts at a time and tamped down with a silver rod until the tube is full, at which point the tube is closed off using a plug of silver tape. After the tube has been packed with superconducting powder and sealed, then the tube is degassed by placing it in a cool oven, in air, raising the temperature to 830°C and maintaining that temperature for five hours. The tube is then drawn in a number of stages down to a diameter of approximately 1.11 mm. The drawing is done in 27 steps in each of which the cross-sectional area of the tube is reduced by approximately 15%. During drawing, the tube is twice annealed at 500°C for between 30 and 60 seconds, when its diameter is 2.51 mm and 1.96 mm.

The 1.11 mm wire is then rolled in a rolling mill with a roll diameter of 200 mm, in stages, to successive smaller thicknesses using roll gaps of 0.80, 0.65, 0.50, 0.40, 0.35, 0.30, 0.25 and 0.22 mm, twice annealing for between 30 and 60 seconds at 500°C, at thicknesses of 0.65 mm and 0.35 mm.

The tape is then cut into eight strips of equal length and stacked in two stacks as shown with one or two metal tapes (about 0.22 mm thick) as required and the stack of tapes wound on a former of ceramic material (with a ceramic paper strip interleaved to prevent bonding of turns). It may be desirable to square the edges of the tapes (by trimming or otherwise) before stacking to minimise risk of creating voids between the columns. The tapes are then heated at 840°C for about five hours to effect diffusion bonding and then, after being cooled to room temperature, rolled in stages to 0.32 mm using successive roll gaps of 1.00 (when there are two metal tapes), 0.80, 0.65, 0.55, 0.45, 0.38, 0.35, and 0.32 mm, annealing under the same conditions as before at 0.80 mm and 0.55 mm.

The composite tape is then heated in air, starting with a cool oven, to 840°C and held at that temperature for 50 hours, cooled to room temperature and rolled once on the same mill with a roll gap of 0.28 mm. Finally it is heat-treated in an atmosphere of 7.5% oxygen balance nitrogen, starting with a cold oven, heated to 825°C, held at that temperature for 40 hours and then cooled over a further period of 40 hours to 785°C. This heat-treatment regime serves to consolidate it, complete texturing and convert the precursor to the desired BISCCO-2223 phase without risking melting of any large volume fraction of the superconducting material.

The embodiment described above has used eight monofilamentary constituent tapes 2 and a final thickness between 0.25 and 0.3 mm. However, more or fewer tapes can be used and the width, thickness and number of sub-stacks varied depending upon the application of the tape and the relevant (but conflicting) requirements for capacity and flexibility. In most cases the balance of thicknesses and rolling



reduction should be such that the filament thickness is generally in the range 10-40 µm, but preferably close to the lower end of that range.

Twisted (or untwisted) multifilamentary tapes, if desired with different numbers of filaments, different pitches and/or different twisting sense or direction, could also be stacked and bonded together and provided with or without the outer layers of silver/silver alloy, but the invention is not expected to show the same benefits for twisted tapes as for untwisted ones.

CLAIMS

1 A composite superconducting tape comprising a multiplicity of constituent superconducting tapes stacked parallel to one another with major faces in contact, and *characterised in that* at least some of the constituent tapes have widths not greater than half the width of the composite superconductor and are laid edge to edge with each other.

2 A composite superconducting tape as claimed in claim 1 in which all the constituent superconducting tapes have a width that is substantially a simple fraction of the width of the composite tape so that they form two or more substacks with aligned zones between them which contain no superconducting material.

3 A composite superconducting tape as claimed in claim 2 in which the said simple fraction is a half, so that there are two sub-stacks.

4 A composite superconducting tape as claimed in any one of claims 1-3 comprising at least one full-width tape of silver or silver alloy bridging from tape to tape.

5 A composite superconducting tape as claimed in claim 4 in which one full-width metal tape is present at one end of the stack.

6 A composite superconducting tape as claimed in claim 4 in which two full-width metal tapes are present, one at each end of the stack.

7 A composite superconducting tape as claimed in claim 6 in which the two metal tapes are of unequal strength.

8 A composite superconducting tape as claimed in any one of claims 1-7 in which the superconducting tape is diffusion-bonded and all its elongate components extend longitudinally.

9 A composite superconducting tape as claimed in any one of claims 1-8 in which the constituent tapes are all powder-in-tube superconducting tapes.

10 A composite superconducting tape substantially as described with reference to either Figure 1 or Figure 2.

ABSTRACT

Superconducting Tapes

A composite superconducting tape comprises a multiplicity of constituent superconducting tapes stacked parallel to one another with major faces in contact, and at least some of the constituent tapes have widths not greater than half the width of the composite superconductor and are laid edge to edge with each other.

Preferably all the constituent superconducting tapes have a width that is substantially half, or another simple fraction, of the width of the composite tape so that they form two or more substacks with aligned zones between them which contain no superconducting material. This will normally require the addition of a full-width tape of silver or silver alloy to bridge from tape to tape, to provide sufficiently strong mechanical connection between the substacks. Preliminary experiments suggest that this structure has substantially improved critical current compared with a stack of the same overall dimensions and composition with all full-width superconducting tapes; perhaps because of magnetic de-coupling between the substacks.

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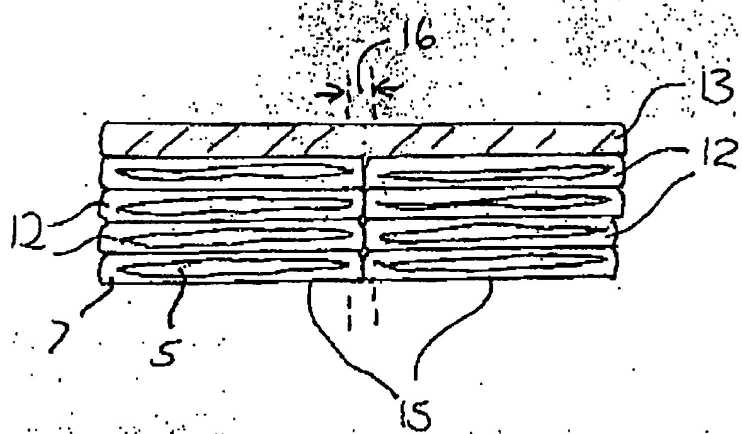

Fig 1

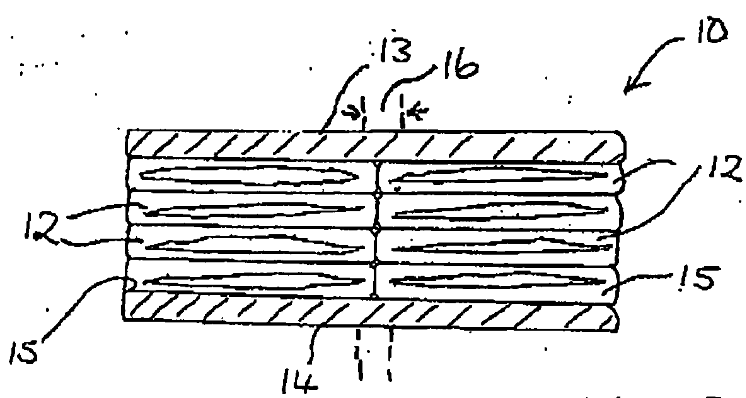

Fig 2